Efficiency Testing of a Williams Crossflow Turbine

An Undergraduate Honors Thesis
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Michael Scherping

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Advisor: Dr. Clarissa Belloni

Abstract

In 2016, renewable energy made up only 10% of total U.S. energy production, with hydropower making up a quarter of that 10%. As large rivers have been mostly developed, the market for expansion of renewable energy through hydropower must now look to the smaller rivers. There are over 80,000 small dams spread throughout the United States that have the potential to be used for renewable energy production. Many of these rivers contain low-head dams or weirs that are not yet used for hydropower production. This project's purpose is to evaluate low head hydro turbines that can be easily installed in different rivers without changes to the dam or weir. This project focused on the turbine design, in particular, blade shape, as well as a comparative study of the turbine operating in conjunction with a debris screen. An initial prototype turbine was built by Central State University, which was modified for this project. The testing involved parametric analyses to determine the optimal operating conditions and design parameters yielding the highest turbine efficiency. The first half of the project was dedicated to maintaining turbine rotation, belt driven gear alignment, data recording techniques, and flow input into the turbine. The second half focused on generating power curves and evaluate the performance under debris screen condition. With increased development and installation of low head turbines in the available market, these turbines could increase renewable energy production by 2.5%.

Acknowledgments

I want to thank Dr. Clarissa Belloni for all her guidance through my final two years of college. First, for teaching me in both Thermodynamics and Fluid Mechanics. Secondly, for teaching me how to conduct research, write reports, and general engineering practices that I will carry with me into my career.

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Contents

Nomenclature

A_p	Cross-sectional area of pipe
A_t	Area of the orifice
C_d	Discharge coefficient based on sharp edge orifices
f	Belt frequency
g	Acceleration from gravity
Δh	The difference in height from the orifice flow manometers
I	Current
L	Belt length
P_g	Power from generator
P_t	Power from the turbine
Q	Channel flow rate
R_e	Radius from the center of the blade
T	Belt tension
V	Voltage
ρ	Density
ω	Turbine angular velocity
WCT	Williams crossflow turbine

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Chapter 1: Introduction

Chapter 1 is an introduction to the project, looking into the market available for water turbines and a brief introduction to the Williams crossflow turbine. It concludes with a general overview of the remaining chapters of the thesis.

1.1: Background

As the world continues forward with new technology and products, energy to power all of these will have to progress as well. In order to meet this demand in an environmentally friendly way, renewable energy needs to be expanded. In 2017, the U.S. Energy Information administration recorded that only 10% of the total energy consumption came from renewable energy and of that 10%, hydroelectric was 25% (Administration, 2018). Most of the hydroelectric energy production comes from large dams on large rivers that have a great amount of energy potential. However, there are 80,000 small dams spread all through the United States that have the potential for energy production (B. Hadjerioua, 2012). Although these smaller rivers cannot produce a great amount of energy, there is still the potential that can be capitalized on. For these small river energy productions to be profitable, they must be low cost to build and install, have easy to access for maintenance and be able to work in many different environments. Building a turbine that can fit these requirements and working in all these potential rivers across the country, it is estimated that this could increase renewable energy production from hydropower by 80% (Boualem, 2015).

1.2: Williams crossflow turbine

The Williams crossflow turbine (WCT) is a low head turbine designed to generate power by using the head created by a weir or small dam in a river. It was designed by Mr. Fred

Williams Jr. (U.S. Patent # : 5,882,143, Date of Patent: Mar. 16 1999 Low Head Dam Hydroelectric System). This turbine being a crossflow turbine means that the turbine's axis is oriented perpendicular to the water flow velocity. The turbine has similarities to the design of the Ossberger or Banki-Michell turbine, yet is very different in its location for application and size. This turbine is aimed to be installed at moderate head drops in rivers, like a waterwheel, and can handle wildlife and debris thanks to a screen and metal casing that surrounds the turbine. Turbines like the Ossberger are connected to controlled water flow from inside of buildings that filter the water. Thus, the WCT shares elements of both Ossberger turbines and waterwheels. Figure 1 shows an engineering schematic of the turbine installed in a river behind a weir. However, the blade design from Figure 1, has been changed for more testing.

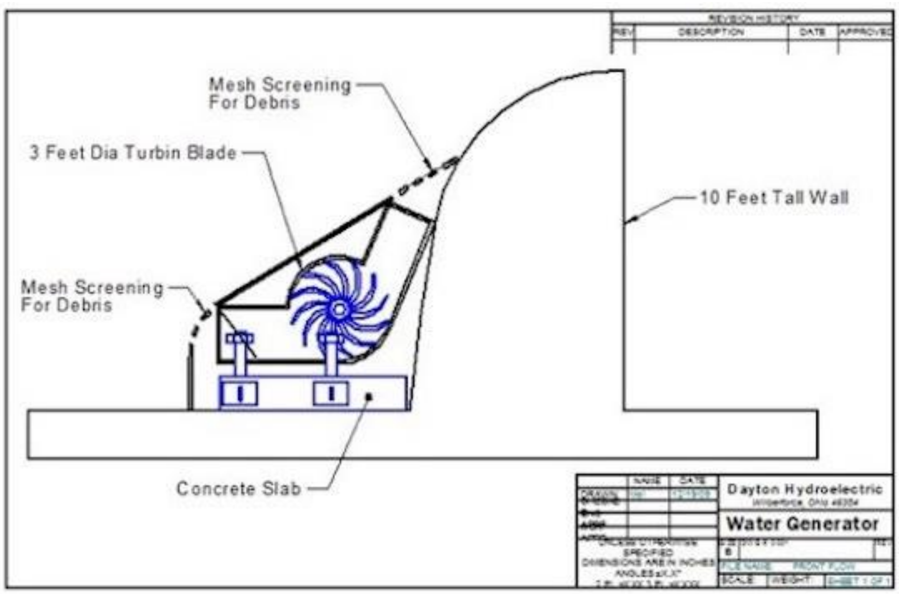

Figure 1: Williams crossflow turbine

1.3: Purpose

The WCT has been developed by kWRiver in research collaboration with Central University's Department of Water Resources Management. The goal is to produce a highly efficient turbine that is enclosed in a protective casing to be installed in low head rivers. There is a large market to be capitalized on by developing a modular turbine that can be installed in all types of rivers throughout the country. Dr. Belloni's Hydro and Aero Energy Group is performing an independent efficiency analysis of the turbine to help with the design change as the turbine is scaled up for the market.

1.4: Overview of Thesis

My role on the project was to perform experimental tests on a scaled down version of a WCT at Central State University. First, I did an overall analysis of the testing facility and general maintenance on the existing turbine. Second, I repeated previous tests to verify that the results were repeatable and accurate. Lastly, I performed three different tests to help with the efficiency design of the turbine. In the first test, two different blade designs (Figure 21, Figure 22) were run to find optimal turbine efficiency. In the second test, flow shields (Figure 15) were inserted into the flume to determine the percentage of flow passing through the turbine. In the third test, a hydro screen (Figure 30) was used at the inlet of the turbine to see its effects on the power output.

This thesis is split into 9 chapters that highlight general low head turbines and testing, measuring techniques, and efficiency results. Chapter 2 is a literature review of low head turbines, crossflow turbines, and experimental studies on crossflow turbines. Chapter 3 is an overview of the Williams crossflow turbine, focusing on the design and previous tests. Chapter 4 discusses the model WCT, Central State University's McLin flume lab, and data collection for the provided equations. Chapter 5 discusses changes made to the testing facility for different data results. Chapter 6 is an overview of the results from the unobstructed flume flow. Chapter 7 is an overview of the results from the modified flume flow. Chapter 8 is an overview of the hydro screen flow results. Lastly, Chapter 9 is a summary of the report and expands on future work.

Chapter 2: Literature Review

Chapter 2 describes the parameters for a low head turbine and the different types of turbines that can be used in this environment. Then, a general overview of different testing that has been done on crossflow turbines.

2.1: Low Head Turbines

A low head turbine usually employs a head of 15 meters or less to produce energy, while also generally not requiring a dam or retainer wall to create the hydraulic head (Boualem, 2015). There are many different types of low head turbines that are being designed to capitalize on this market. The two main types of turbines are impulse and reaction. Most low head turbines are an impulse design. Impulse turbines, like the Pelton, Ossberger, Banki-Michell, and waterwheels use the kinetic energy of the water to push the blades which spin the turbine. In a Pelton turbine, a water jet is directed onto the blades as a force to spin the turbine. The Ossberger and Banki-Michell (Crossflow Turbine, 2018), allow the water to flow through the machine and use the pressure difference (lift) over the blades to spin the turbine. While the Pelton and Ossberger turbines have controlled and filter water flow, turbines like the waterwheels are "run-off-the-river" that have a mix of debris and wildlife in the water. The waterwheel is one of the oldest of the turbines and uses the flow of the river to push the blades, spinning the main shaft (Muller, 2004).

2.2: Crossflow Turbines

The Ossberger turbine (Figure 2) has water flow that passes through the inlet to the chamber of the machine and out the outlet, yet it does not fill it up fully (Ossberger Crossflow Turbine, 2017). The remaining space is filled with air which creates a negative pressure inside the turbine cavity and is called the ‘suction head’ across the turbine. The positive water pressure from the upstream side of the rotor is called the ‘pressure head’ and the sum of the pressure and suction heads equals the net head across the hydro system. (Crossflow Turbine, 2018). These types of turbines work better for low heads because they get higher efficiency from the blade design with limited kinetic energy. The Banki-Michell turbine has a similar design to the Ossberger turbine that is optimized for similar conditions (Breslin, 1980).

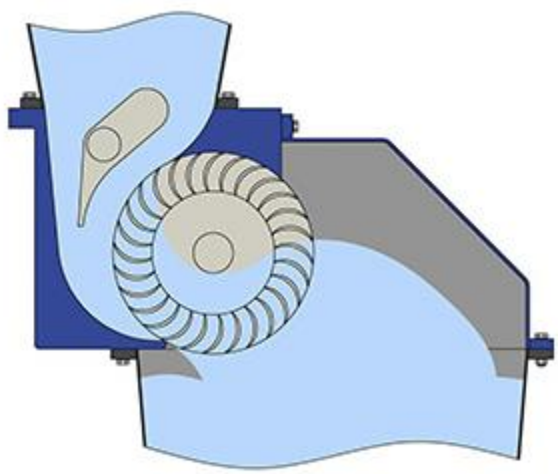

Figure 2: Ossberger crossflow turbine

Waterwheels are one of the oldest forms of hydraulic power and used the power of rivers for thousands of years to power technical equipment and mills. In the modern world, waterwheels spin generators to produce electricity which can be used for homes or sold on the grid. There are three major types of waterwheels: Overshot Wheel (Figure 3), Breast Wheel (Figure 3), and Undershot Wheel (Figure 3). Of these, the Breast Wheel is best for the low head and are typically used for head differences of 1.5 to 4m, and flow rates of 0.35 to 0.65 m^3/s per m width (Muller, 2004). Water wheels are used in rivers, creeks, and many more types of water potentials.

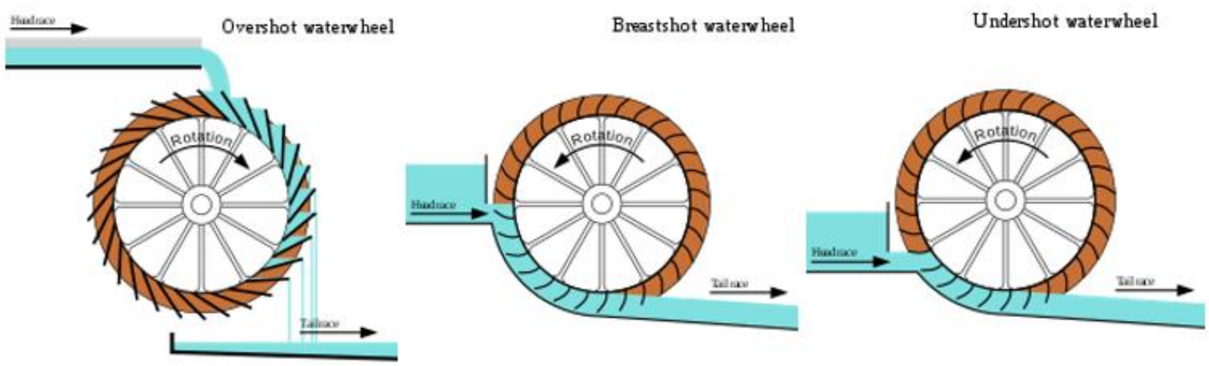

Figure 3: 3 Types of water wheels (Water Wheel, 2017)

2.3: Experimental Studies of Crossflow Turbines

Crossflow turbines are a prominent turbine design for low head rivers that are the subject of many studies. For turbines like the Ossberger, they have a mostly controlled system to help preserve the machine and yield the highest efficiency. They have large upfront costs to build the infrastructure to run the turbines. Therefore, most testing is done in a similar setting with control piping, flow, and loading. An example of a testing facility was reported by a team at Kathmandu University. This group developed a crossflow turbine test rig for testing a blade design (Figure 4) (Shrestha, 2017). Through this system, they solved for shaft power output and efficiency figures to find the best blade designs. This system of testing is very different than the test set up explored in Chapter 4. The system in Chapter 4 is different because a crossflow turbine was tested in a “run of river” flume style.

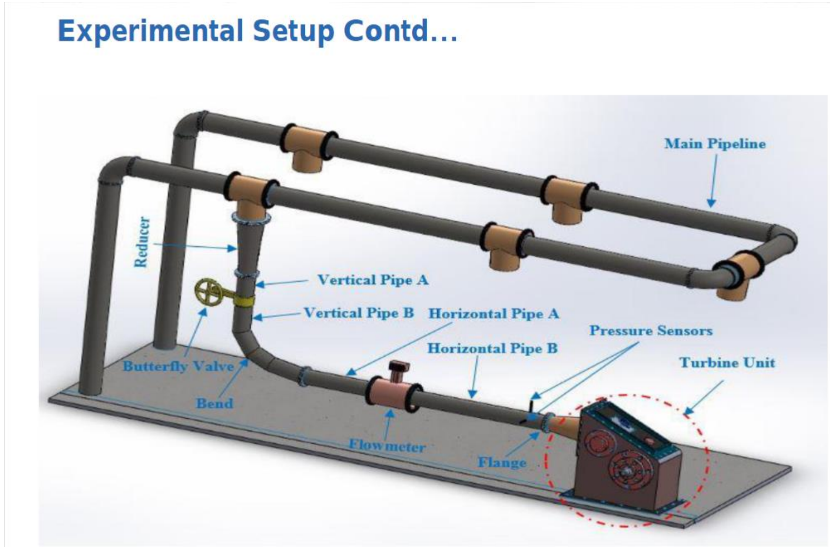

Figure 4: Layout of crossflow test rig (Shrestha, 2017)

In addition to physical testing of turbines, CFD models are another way to design and analyze hydro turbines. The work done by Mr. Adhikari and Mr. Wood in their analysis of experimental and computational studies of a crossflow turbine efficiency testing shows the benefits of a well-designed CFD model (Adhikari, 2018). In their work, they narrowed down key design requirements to significantly increase the efficiency of the system. The first area that will make the biggest impact on the efficiency is the total conversion of head into kinetic energy in the nozzle. The second area is matching the nozzle and runner designs to allow for optimal fluid flow and power generation. Through a CFD modeled turbine, they were able to increase the overall efficiency of a turbine without having to build a testing facility or model turbine.

Mr. Pokhrel developed a computational model of the Williams crossflow turbine in order to analyze the efficiency testing of the turbine (Pokhrel, 2017). Employing a CFD model enables more rapid testing of the different number of blades, blade arrangement, inlet design, and many more key parameters compared to an experimental. This CFD modeled concluded that a nine blade turbine produced more power than a twelve blade turbine for the operating conditions in the Central State University Lab. This tool can be used to improve the design of the WCT and help design a full scale WCT for run-of-the-river applications.

Chapter 3: Williams Crossflow Turbine

Chapter 3 focuses on the design of the Williams crossflow turbine and previous testing on it.

3.1: Intent of Design

The Hamilton, OH startup company kW River has partnered with Central State University as well as The Ohio State University to help with the design of the WCT. The intent of this turbine design is the installation on existing weirs in the river, with only minimal infrastructure modification, while also designing an accessible system allowing for maintenance to be performed on the river bank. At the same time, the design should be environmentally friendly, to ensure the safety of animals and people in the river. These goals can help keep the costs low which will increase the potential for this hydropower product.

There are unique features about the WCT that separates it from all other low head turbines (S. I. Sritharan, 2013) that allow it to capitalize on the lead head energy market. First, it is designed to be able to be mounted fully submerged underwater behind a weir or dam, which allows it to be installed into more low head rivers. The turbine is protected in a metal casing that slants down (Figure 1), which lets any wildlife or human, to go over the top without getting injured. Additionally, there will be a screen covering the inlet to prevent debris, like trash, or plants, as well as small fish, from getting inside the turbine. This is important because it will allow it to be installed in many types of rivers across the country..(B. Hadjerioua, 2012).

There are specific features of the turbine that are still undergoing modifications in testing to optimize efficiency which will be highlighted in greater detailed throughout the report. These features include blade design and the number of blades, screen design, and length of the inlet. I have performed testing on each of these features to build a data bank that in concert with CFD simulations will help optimize the efficiency of the turbine design.

3.2: Previous Tests Performed on Turbine

The first iteration of the WCT was designed and tested at Central State University's Department of Water Resources Management by Dr. Sritharan, Mr. Williams, and Mr. Shirk. Mr. Williams created the first design and patented the turbine. Dr. Sritharan and Mr. Shirk performed a hydraulic analysis of the turbine to optimize the design and project expansions (S. I. Sritharan, 2013). These tests were performed on a 15:1 model version of the WCT in a flume at Central State University. I used this report by Dr. Sritharan (S. I. Sritharan, 2013) as a guideline for the tests performed throughout this project.

For these tests, the flow rate of the flume was set using the orifice flow meter (Figure 10). The turbine was positioned directly behind the weir in the middle of the flume (Figure 13), which left room between the turbine and glass sides. The turbine was loaded with both an electrical and mechanical load. The electrical load was delivered through the generator by applying a load with light bulbs (Figure 6). The mechanical load was delivered through a belt tensioner that applied friction forced on the belt drive (Figure 12). The electrical load was used to determine generator power (Equation 1) while the mechanical load was used to determine turbine power (Equation 5). For the tests highlighted in Chapters 6-8, only the mechanical load was applied. The electrical loading was not used because the generator had lost efficiency and needed to be replaced.

In their project (S. I. Sritharan, 2013), the authors tested differences in the number of J blades, water volumetric flow rate, water submersion, electrical loading, and an overall efficiency rating. For the given blade design, they found that 9 blades produced the greatest voltage at full load. The same 9 blade arrangement was used for all tests performed in this project that are highlighted in Chapter 6-8.

Chapter 4: Experimental Setup

Chapter 4 describes the model turbine used for testing, the testing faculty, the data recording techniques, and the equipment used throughout the project.

4.1: Model Turbine Design

The current testing is being performed on a 15:1 scaled down model of the WCT at Central State University's Department of Water Resources Management (Figure 5). The turbine and weir are set inside a flume with the water passing over the weir into the inlet of the turbine (Figure 6). The turbine spins a gear which transfers the power through a belt to the generator (Figure 7). The belt drive is used to transfer the power to the generator due to the limited space inside flume. This is not a typical testing design for a turbine and will be explored further in the report. A load is placed on the generator by using 6 lightbulbs as resistors to modulate the rotational velocity of the machine. The current, I, and voltage, V, are then read with a multimeter to determine power, P, see equation. 1.

$$P = I * V \tag{1}$$

Due to generator issues, it was not possible to use the electric load on the turbine for the experiments described in this thesis. In order to modify the rotational velocity, the belt tension was varied and the power computed using belt tension, frequency and rotational velocity see equation 2, 4, 5.

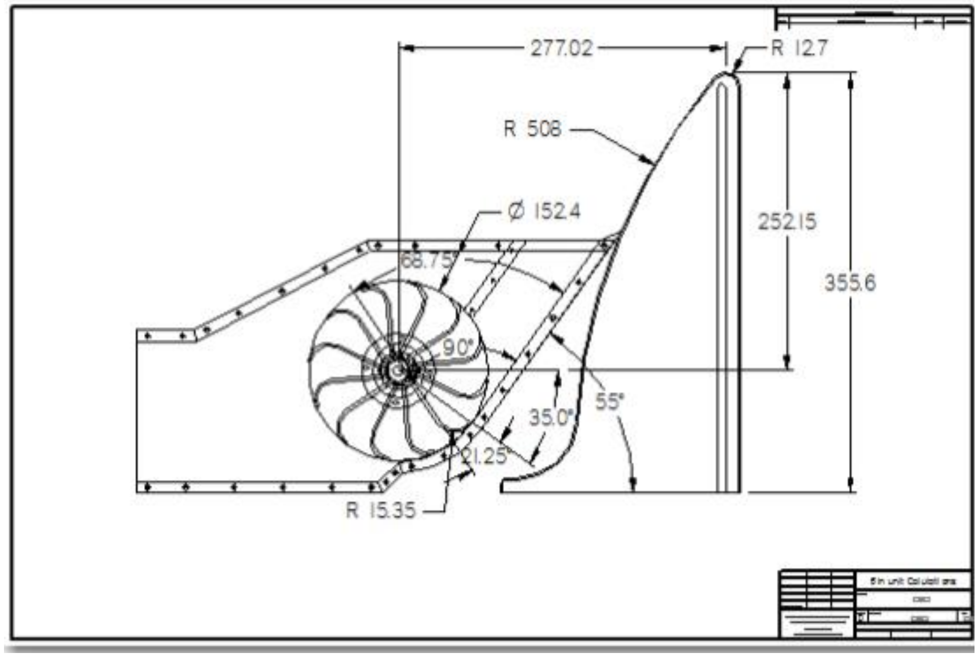

Figure 5: WCT model sketch

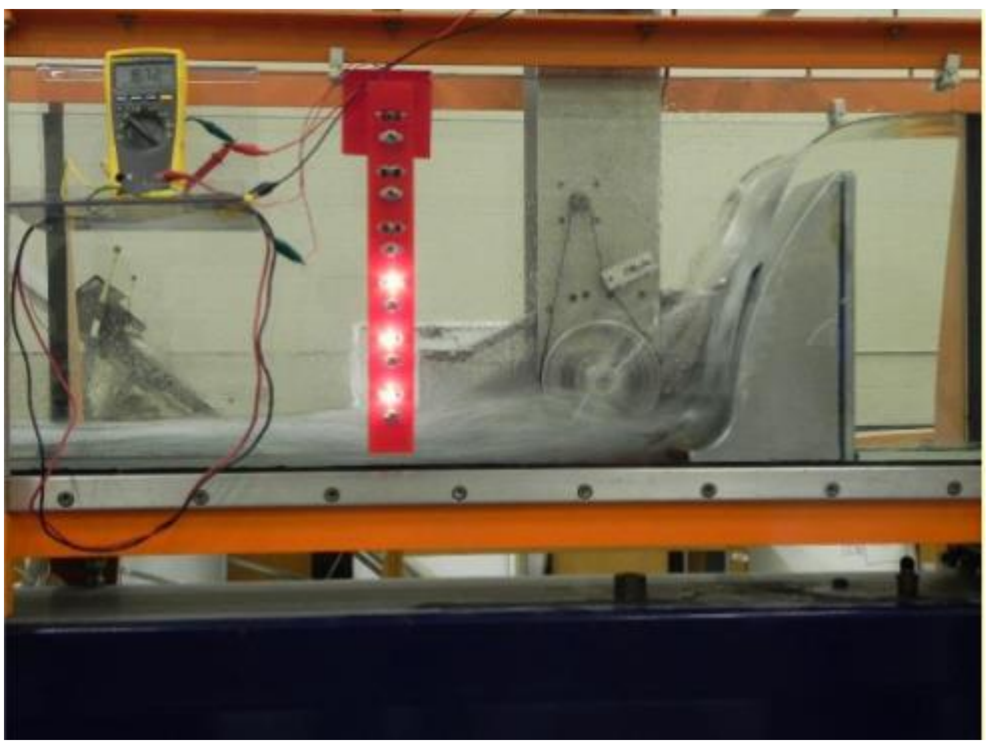

Figure 6: WCT in testing

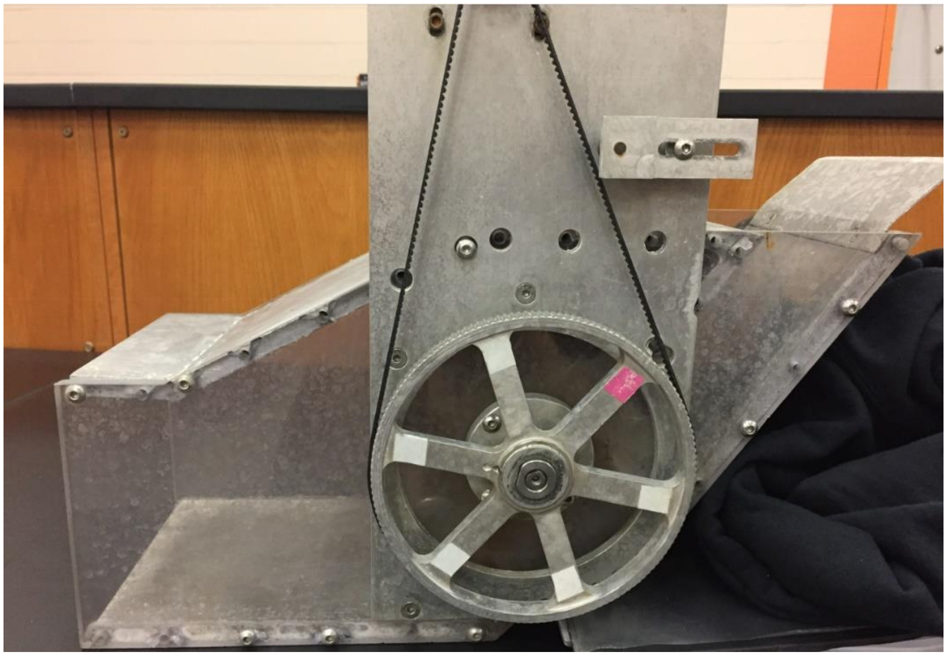

Figure 7: WCT model

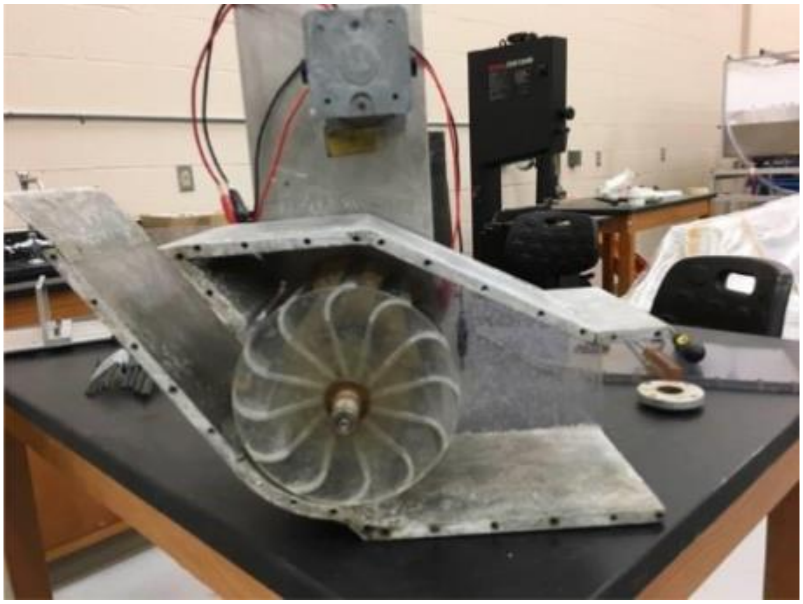

Figure 8: WCT internal view

4.2: Testing Facility

All experimental testing was performed at Central State University's Department of Water Resources Management. In the facility, a tilting testing flume is installed. In this flume, a weir and the low head turbine are installed for testing (Figure 9). The turbine is installed directly at the foot of the weir to generate power from the head drop over the weir. The channel flow rate provided by a pump is set by turning a valve and calculated using an orifice manometer (Figure 10). The water then fills up the flume until the head is high enough to overtop the weir and run through the turbine, thus delivering power.

Figure 9: Testing facility

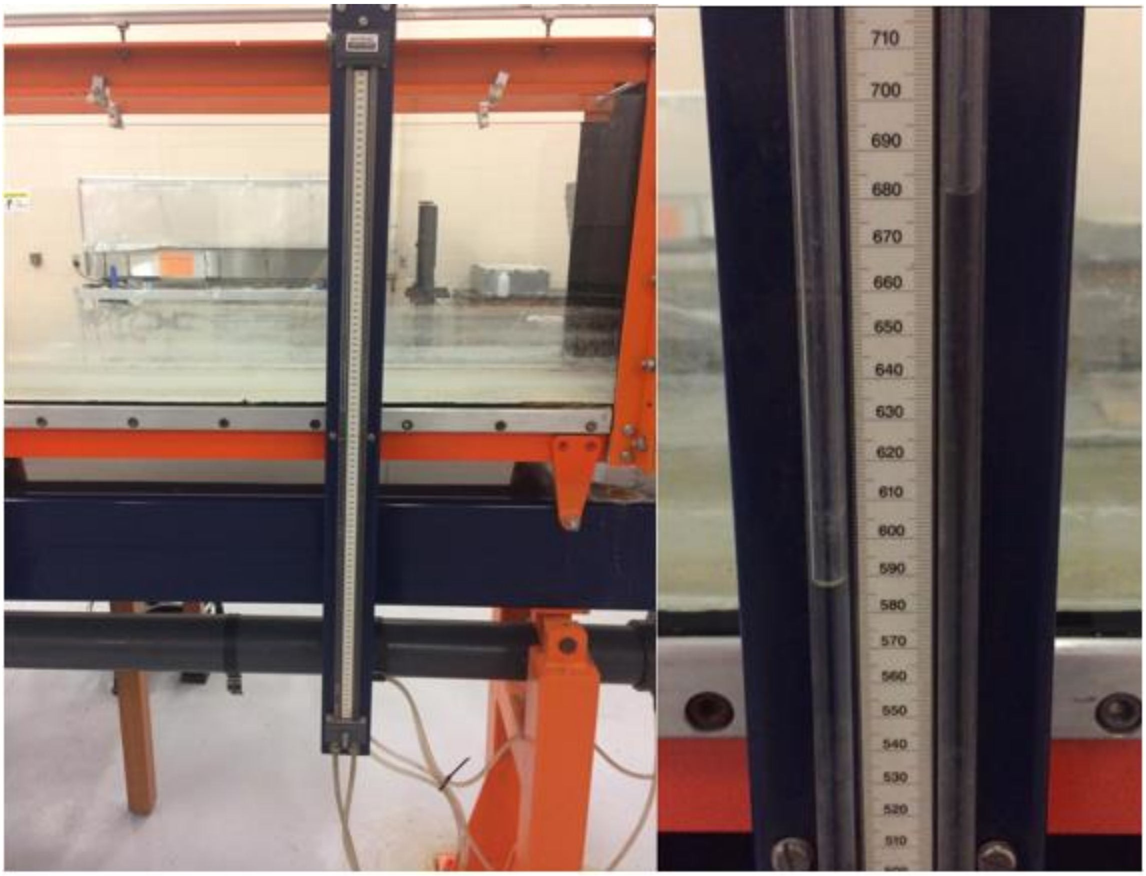

Figure 10: Orifice flow meter

4.3: Data Recording Techniques

The main measurement parameters to be measured for these experiments were channel flow rate, turbine rotational velocity, turbine belt tension, and power generated by the generator on the turbine. The channel flow rate was solved by using the difference in height taken from the orifice manometer with the equation for the orifice manometer (Equation 2) (S. I. Sritharan, 2013).

$$Q = \frac{A_t C_d}{\sqrt{1 - \left(\frac{A_t}{A_p}\right)^2}} \sqrt{2g(\Delta h)} \tag{2}$$

Where A_p is the cross-sectional area of the pipe, A_t is the area of the orifice, g is acceleration due to gravity, C_d is the discharge coefficient based on sharp edge orifices $C_d = 0.742$, and Δh is the height difference read on the manometer.

The turbine's measurements were performed using a stroboscope (Figure 11), belt frequency measurer (Figure 11), multimeter (Figure 11), and belt tensioner (Figure 12). The stroboscope was aimed at the driving gear with 5 white pieces of tape and 1 pink piece of tape, see Figure 12. The stroboscope frequency was increased until the pink piece of tape appeared to have stopped moving. Once this point was reached, the rotational velocity, given in rpm was recorded. One of the key issues with a stroboscope is that the exact rotational velocity is not possible to be determined without a secondary verification. Once the stroboscope is matched to the speed of the gear, the frequency could be doubled or halved continuously, and the gear would still appear to be held constant. So, a slow-motion camera on an iPhone 6 was used to record the gear for 3 seconds. Then the video was played to count the number of rotations in the three-second video. This could give a close estimate to rates on the stroboscope to determine at what frequency the gear was spinning (3) (S. I. Sritharan, 2013). This will be further explored in Chapter 6 analysis of the unobstructed flume flow results.

$$\omega = \frac{rotations\ from\ video}{3\ [seconds]} * \frac{60\ [seconds]}{1\ [minute]} = \frac{revolutions}{minute} \qquad (3)$$

Figure 11: Data recording tools from left to right: belt frequency measurer, stroboscope, multimeter

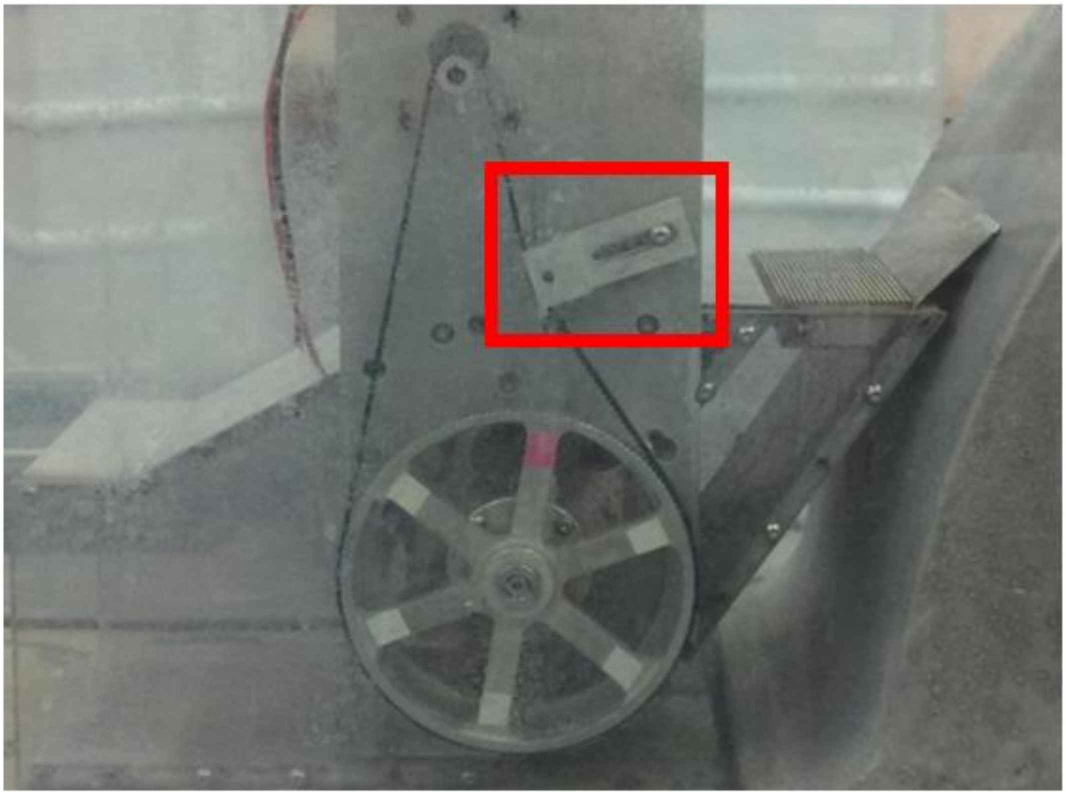

Figure 12: Belt tensioner as mounted on turbine driving belt

Next using the belt tensioner to set the tension, the belt frequency measurer (Figure 11) was aimed at the belt while the belt was struck with a finger. It would measure the frequency of the belt which could be used to determine its tension (equation 4) (S. I. Sritharan, 2013).

$$T = 4\rho f^2 L^2 \tag{4}$$

In equation 4, ρ is the density of the belt, f is the frequency measured by the belt frequency measurer in Hz, and L is the length of the belt.

To solve for the mechanical power (Equation 5) generated by the fluid flow through the turbine, the rotational velocity of the turbine and tension of the belt are employed according to the following equation (S. I. Sritharan, 2013).

$$P = \frac{2\pi T r_e \omega}{60} \tag{5}$$

Where r_e is a geometry constant for the radius of the center of the blade from the axis which is set at R_e = 0.685292 [m].

Alternatively, the power generated by the generator can be read by taking the voltage and current of the generator. This was accessed by a light bulb resistor network which can be used to load the turbine (Figure 6) and provides an alternate method of modifying the rotational velocity. Note that this final step has not been used as part of the work presented in this thesis.

Chapter 5: Modifications to the testing facility

Chapter 5 focuses on the modifications and corrections to the experimental setup to help make testing more efficient.

The first issue with the testing facility addressed in this project was that the turbine width is smaller than the width of the flume meaning that only a fraction of the channel flow runs through the turbine. Figure 13 shows the top view of the turbine in its testing position, which shows that the inlet only takes up around 50% of the flume's width. To correct this, flow screens were added that guided most the flow into the turbine, thereby increasing the confidence in the flow rate passing through the system (Figure 14, Figure 15, Figure 16). Another benefit from employing the flow screens is the reduced interference between water bypassing the turbine and the belt and the increased visibility inside the turbine casing. In an additional step to control for the flow rate moving through the turbine, the insulation between the weir and the glass was replaced from a small blue silicon tube to a larger clear silicon tube (Figure 17) to decrease the amount of water bypassing the weir.

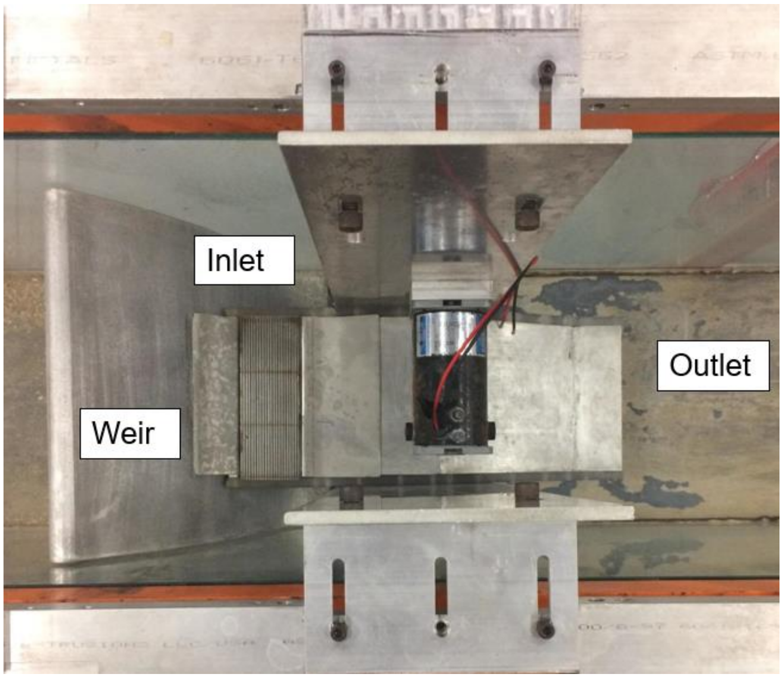

Figure 13: Top View of the turbine in the testing position

Figure 14: Top view of the turbine in the testing position with shields

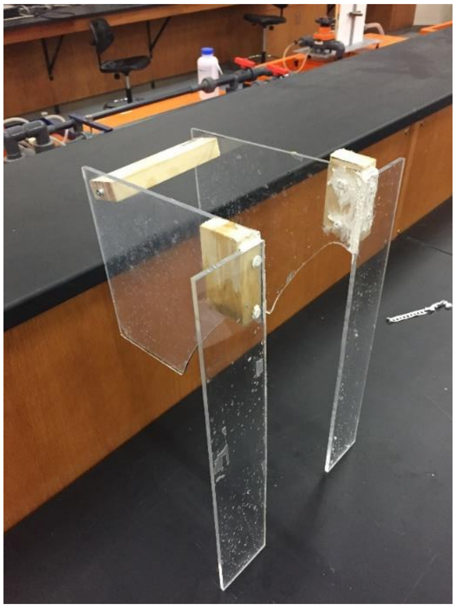

Figure 15: Orthogonal view of flow shields outside of flume

Figure 16: Front view of low shields in the flume

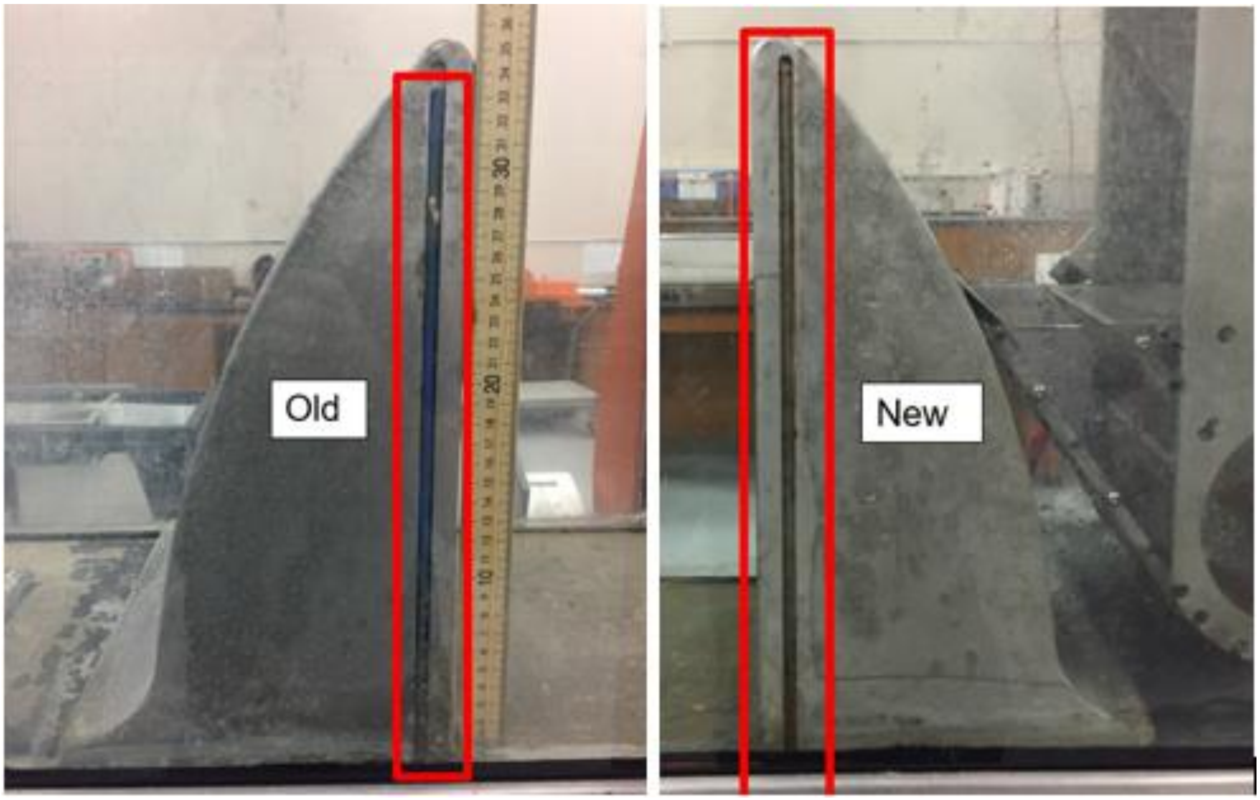

Figure 17: Insulation lining between weir and side glass

The second issue addressed was the belt and gear alignment for the turbine (Figure 18). The screws holding the generator would loosen during turbine operation. This would cause the gear attached to the generator to move resulting in the belt slipping off, therefore preventing any tests from being run. The generator was refitted with upgraded bolts and fasteners to reduce this in future testing. However, this is not a permanent fix and will need to be monitored as tests continue past this project.

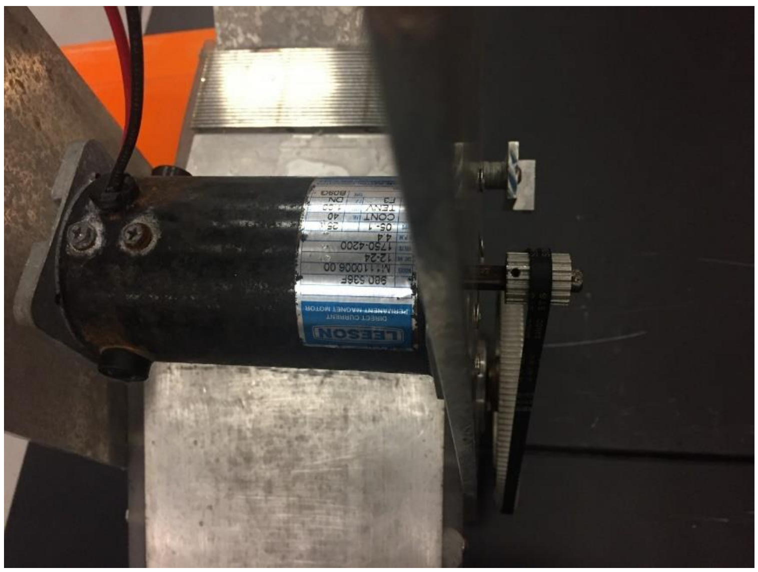

Figure 18: Gear alignment with belt

The third issue addressed was the internal blade clearance of the turbine. After running many tests and moving the turbine frequently, the left side of the casing holding the blades began touching the internal walls of the turbine preventing the turbine from running. Figure 19 shows the left side of the casing which has contact with the wall, while Figure 20 shows the right side which does not have contact with the wall. This issue was fixed by cleaning of the casing and tightening the screws.

Figure 19: Left plate interference with the internal wall

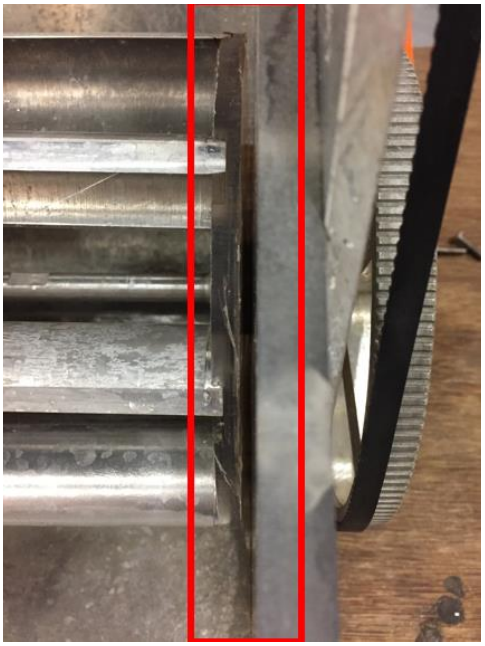

Figure 20: Right plate clearance with the internal wall

Chapter 6: Unobstructed flume flow results

Chapter 6 describes the testing of two different blades types J blades and c blades. These tests were performed without any modifications done to the flow in the flume or into the turbine.

6.1: Test Setup

One of the key areas of interests was the efficiency of the blade design by testing different blades. Past work performed by (S. I. Sritharan, 2013) showed that 9 blades were the optimal arrangement when employing the original J blade design. In this part of the study, a comparison between the J blade (Figure 21) and newer C blade (Figure 22) design was performed in order to determine which produced the greatest amount of hydraulic power. All tests were performed without any screens on the turbine or flow shields, so the water flowed unobstructed into and around the turbine. These tests were conducted using a constant flow rate and then varying the belt tension to create power curves. The three flow rates chosen were 10 L/s, 12 L/s, and 14 L/s. The belt frequency was incrementally increased with each test until at the maximum position.

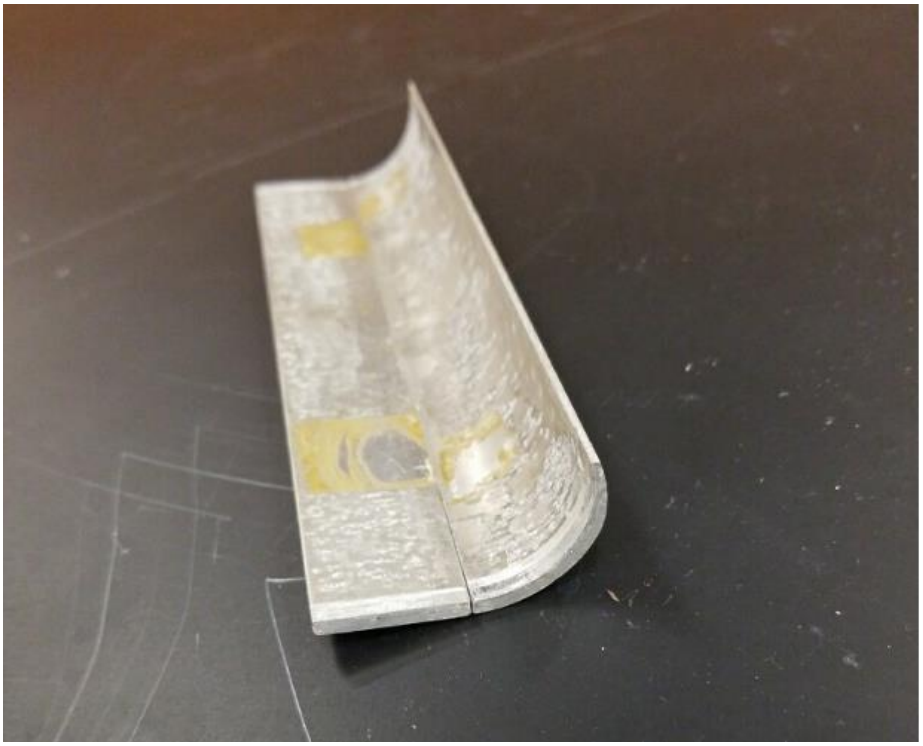

Figure 21: J blade

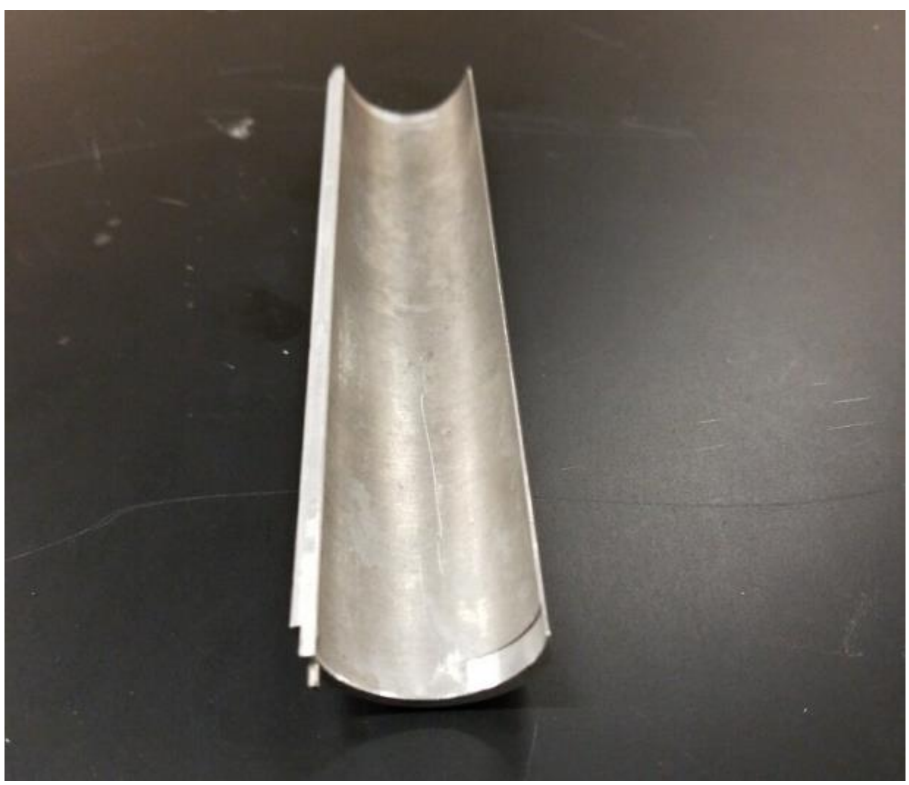

Figure 22: C blade

6.2: Results

The first test was performed at 10 L/s by increasing the belt tension with the belt tensioner until it was at max tension. Figure 23 shows the results of the tests, the C blade performed better by producing more power at a given rotational velocity. However, for the J blade, a lower rotational speed (higher belt tension) was achieved for which higher power output was obtained than the maximum obtained using the C blade configuration. When switching between the J and C blades, the generator gear was moved slightly higher. This allowed the tension to be set at a higher rate than C blade was not able to be tested at.

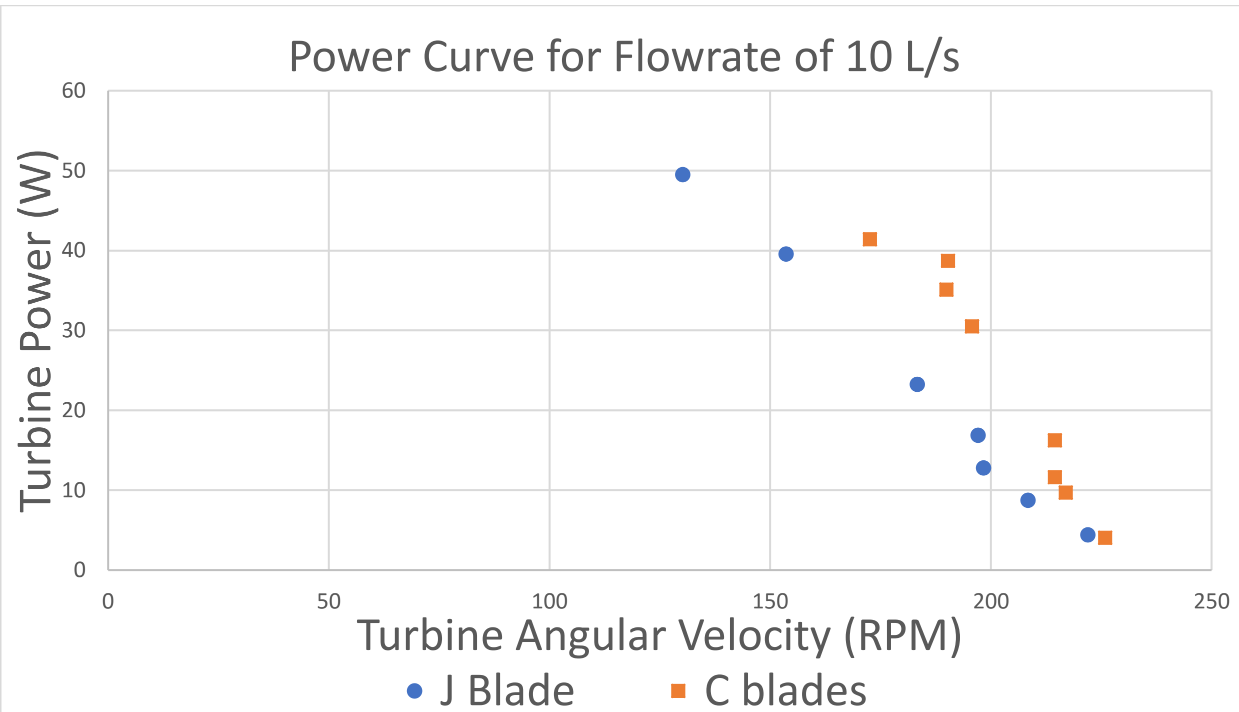

Figure 23: Unobstructed flow power curve 10 L/s

The second test was performed at 12 L/s by increasing the belt tension with the belt tensioner until it was at max tension. Figure 24 shows the results of the tests, the J and C blade produced similar power outputs. Yet, as the same during the 10 L/s tests, the J blade was able to set be a higher belt tension giving it a few higher points at the end.

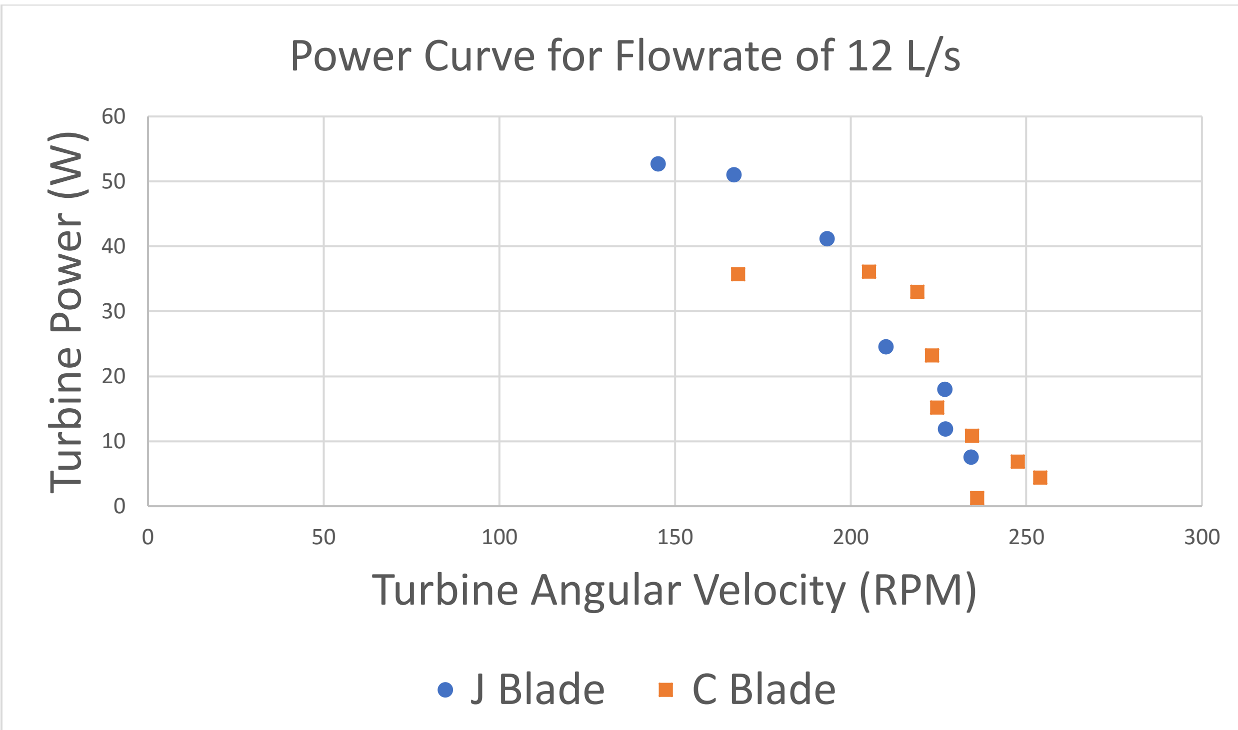

Figure 24: Unobstructed flow power curve 12 L/s

The third test was performed at 14 L/s by increasing the belt tension with the belt tensioner until it was at max tension. Figure 25 shows the results of this test, the J and C blade performed almost the same with very similar curves. With the last test, unlike the tests at 10 and 12 L/s, the belt tension for the C blade test was maxed out at a higher tension than previous tests.

This was a result of precise positioning which gets it slightly higher. The belt tension was maxed at very similar rates for both tests.

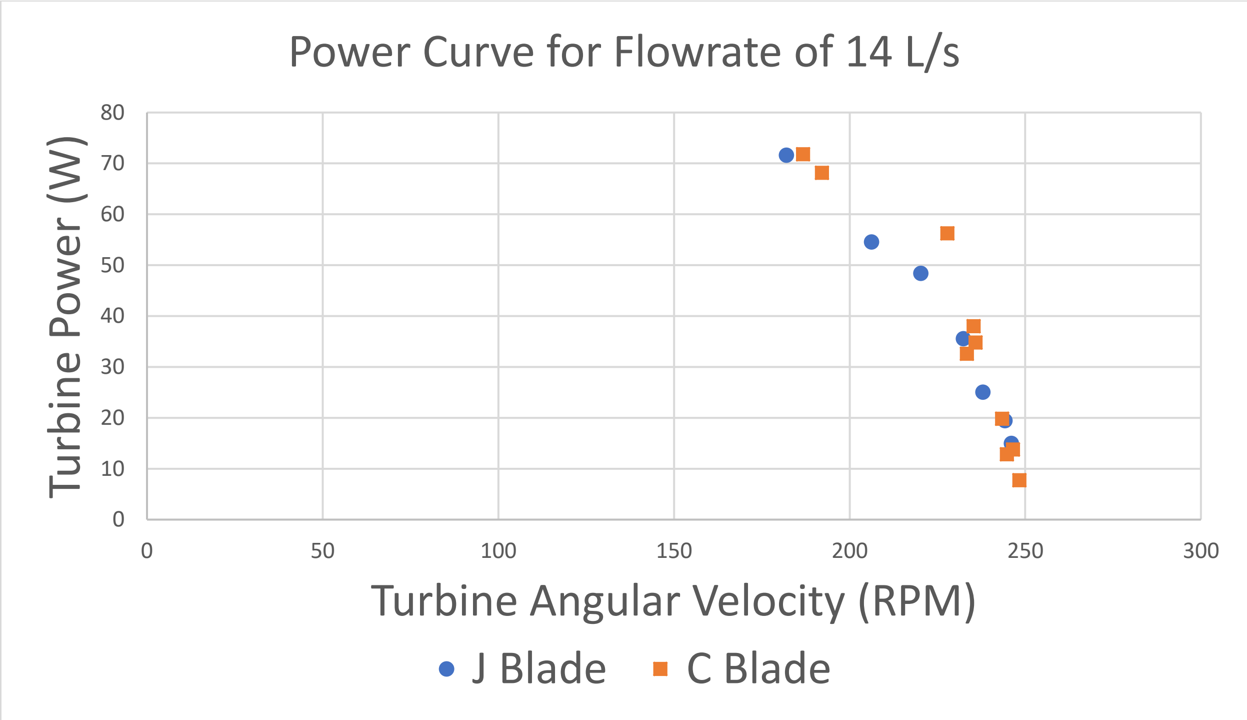

Figure 25: Unobstructed flow power curve 14 L/s

Between the three tests, there was no conclusive evidence as to which blade performs the best for the turbine. Two main areas that could be looked at for testing would be additional flow rates of the current blades and designing new blades. Running more tests with these current blades at different channel flow rates could potentially show a speed that would yield the highest efficiency for the turbine.

Chapter 7: Modified flume flow results

Chapter 7 focuses on altering the flume flow so that all water is forced through the turbine to help clarify the estimated assumption about turbine power.

7.1: Test Setup

The next test was designed to determine what percentage of water was truly flowing into the turbine as the turbine does not stretch across the whole width of the flume (Figure 13). Previous work suggests that approximately 50% of the flow rate passes through the turbine. However, this number was based on an estimate. As knowing the flowrate is crucial for computing the efficiency of the device,

The flow shields were inserted into the flume to force all the water through the turbine (Figure 16). Additionally, the bottom and side edges were sealed with duct tape. Duct tape was used as a watertight seal as required while being able to remove the shields after each test day. The pump power was selected to provide a low flow rate and then slowly increased until the power curve matched that obtained without the flow shields. The methodology for obtaining the power curve was the same as for the previous tests.

7.2: Results

The goal of the test was to match the performance of the turbine with shields installed to that with the unobstructed flow. Figure 26 shows the flow rate with shields compared to all three flow rates from the J blade tests with the unobstructed flow. After carefully increasing flow rates, it was found that 4.2 L/s with shields installed very closely matched 10.19 L/s for the unobstructed flow. Figure 27 shows just the comparison of the two matched test series, in which, it can be clearly seen that a close match was obtained.

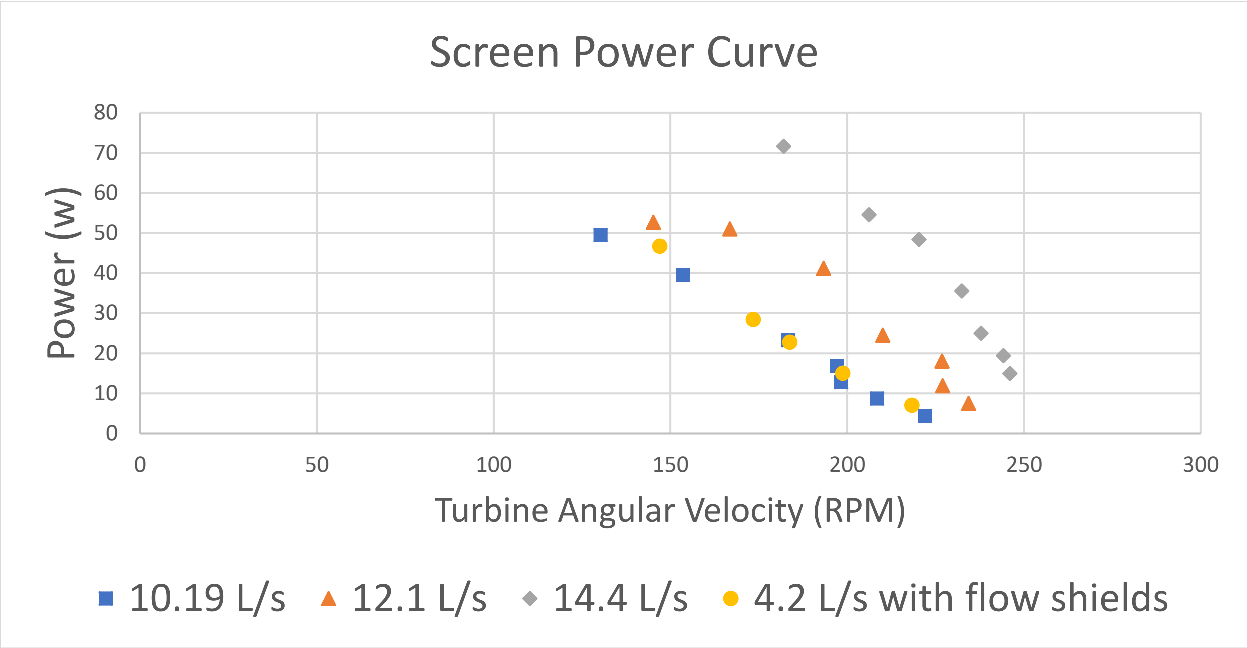

Figure 26: Power curve of J blades with and without flow shields

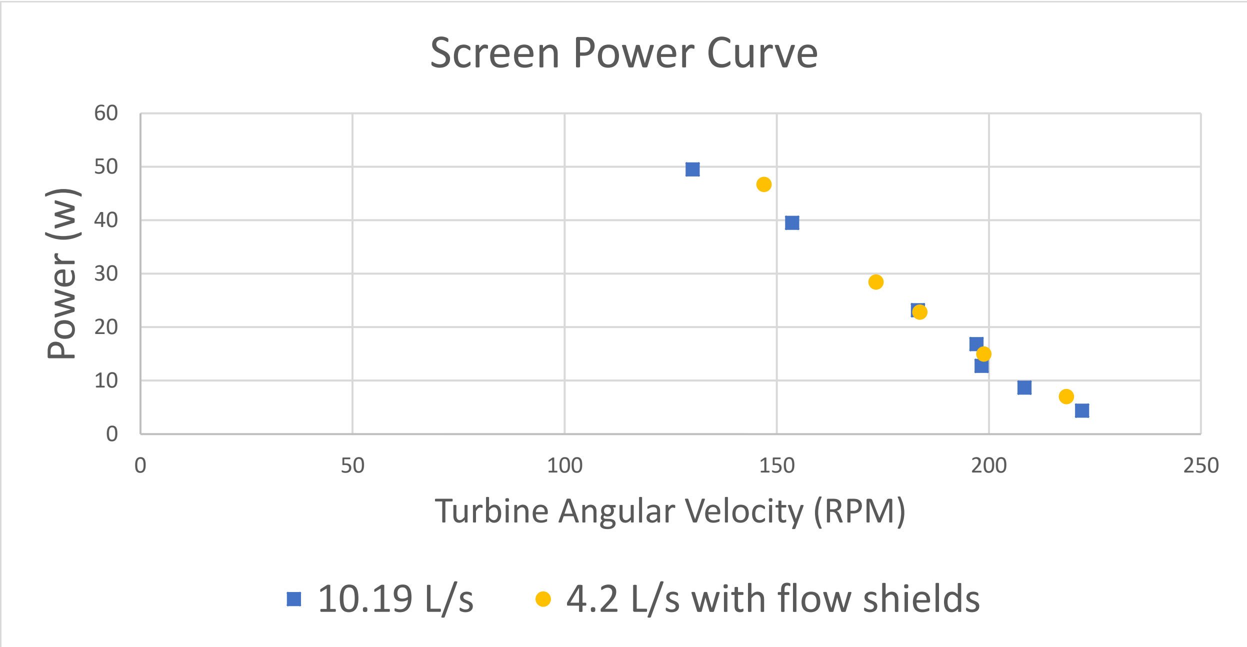

Figure 27: Power curve of J blades with and without flow shields focus on 10.2 L/s and 4.2 L/s

In the earlier work performed on the turbine (S. I. Sritharan, 2013), it was estimated that 50% of the flume flow rate was passing through the turbine. This estimate was based on the dimensions of the turbine spanning approximately 50% of the total width of the flume. However, throughout this project, it was noticed that a large amount of water passes underneath and around the weir, between the inlet ramp and weir, and lastly hitting the inlet casing. While the flow shields were designed to mitigate these flow losses, they also provided the opportunity to investigate the percentage of flow rate lost when no flow shields are present.

The tests show that with the shields installed only 4.2 L/s was needed to match the results obtained at 10.2 L/s without the shields. These results indicate that only 41% of the flume flow rate passes through the turbine when the shields are not installed. Therefore, the initial assumption of 50% flow rate passing through the turbine assumes a flow rate 22% too high.

Chapter 8: Hydro screen flow tests

Chapter 8 focuses on how a Coanda-effect screen, manufactured by Elgin, would affect the power output of the turbine and investigated potential new arrangements/designs.

8.1: Coanda-effect hydro screen

A Coanda-effect hydro screen is designed as a self-cleaning screen that can be used for turbines. These screens work well in rivers with weirs because they use the incline of the weir to block debris while still allowing water to pass through the screen. Additionally, they have minimal clogging and cleaning maintenance which increases their economic value. A typical Coanda-effect hydro screen has wedged shaped wires running horizontally to the water flow (Figure 28). The wires are typically spaced 1 mm or smaller openings. The screen is set at a downward angle so the water flows over the wires, causing the bottom of the water column to hit each wire while the top goes over it. As the water flows over the wires, the offset between the wires can shear a layer of flow of significant thickness off the bottom of the water column and direct it out of the bottom of the screen (Wahl, 2003). The top layer of water which has more debris and wildlife flows harmlessly over the screen and weir without being hurt. If these screens are flat instead of angled, the water would skip over the edges preventing the shearing of the water column. The only flow passing through the screen would be due to gravity deflecting the jet slightly downward between the wires.

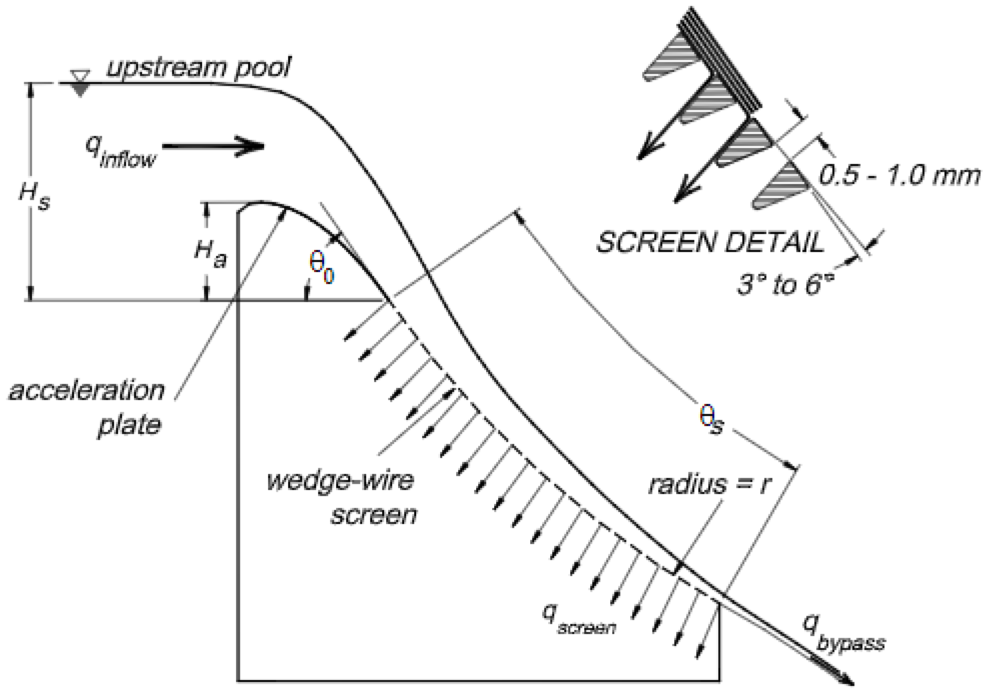

Figure 28: Features, typical arrangement, and design parameters for Coanda-effect screens (Wahl, 2003)

8.2: Test Setup

The last test focused on the effects of a Coanda-effect hydro screen on the input of the turbine to increase screen and turbine efficiency. The screen (Figure 29) was installed into the turbine covering the inlet (Figure 30). The screen was manufactured by Elgin with the intent to block all wildlife and debris while still allowing enough amounts of water to power the generator. This is a self-cleaning screen what will not require any maintenance. This is a crucial design parameter because it keeps the costs of the turbine low which is a main feature of the WCT. The screen is a full sized model and the results would be realistic to a fully scaled turbine.

For these tests, the turbine was run with and without the screen at the same flow rate to determine the low in power. The hydraulic power curve was made by taking the RPM and belt tension to determine power output. This is the same procedure as done in Chapter 6 & 7.

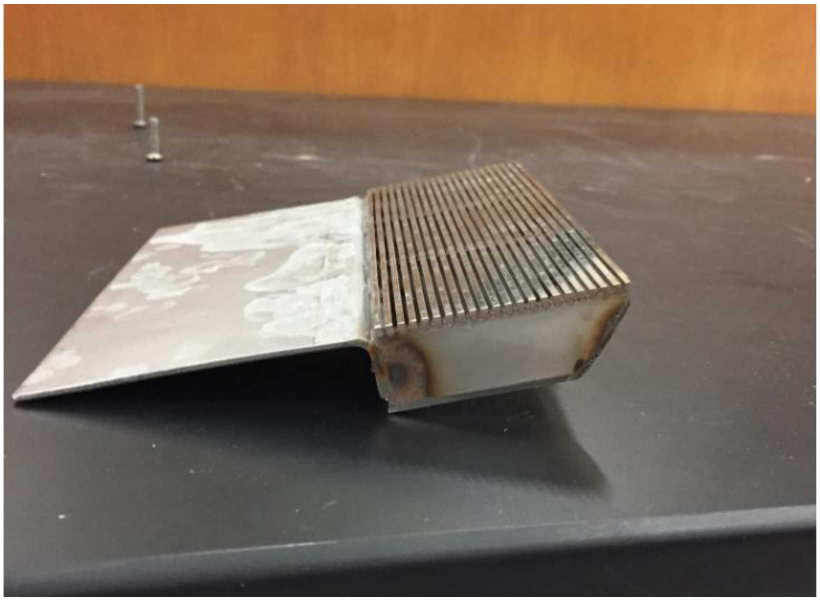

Figure 29: Screen

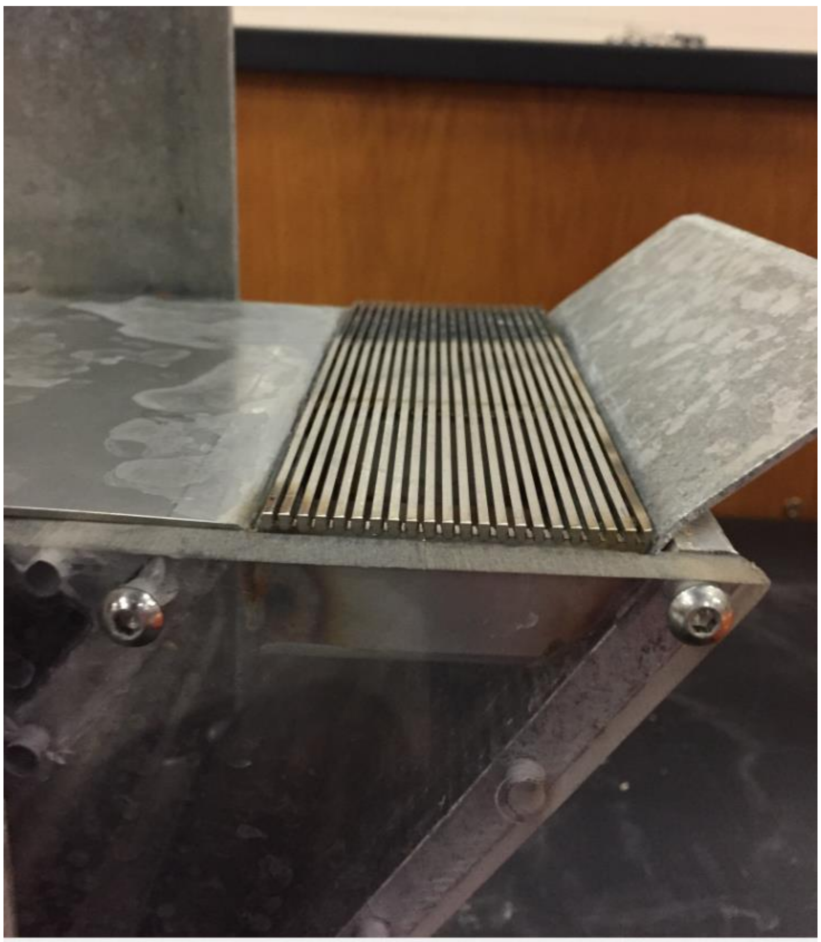

Figure 30: Screen installed in the turbine

8.3: Results

Two different tests were run, at 10.19 L/s and 14.48 L/s to compare to the work in Chapter 6.

Figure 31 shows the results from the test run at 10.19 L/s. As expected, the screens reduced the flow into the turbine which created less power. At 10.19 L/s, the screens blocked around 50% of the water going into the turbine.

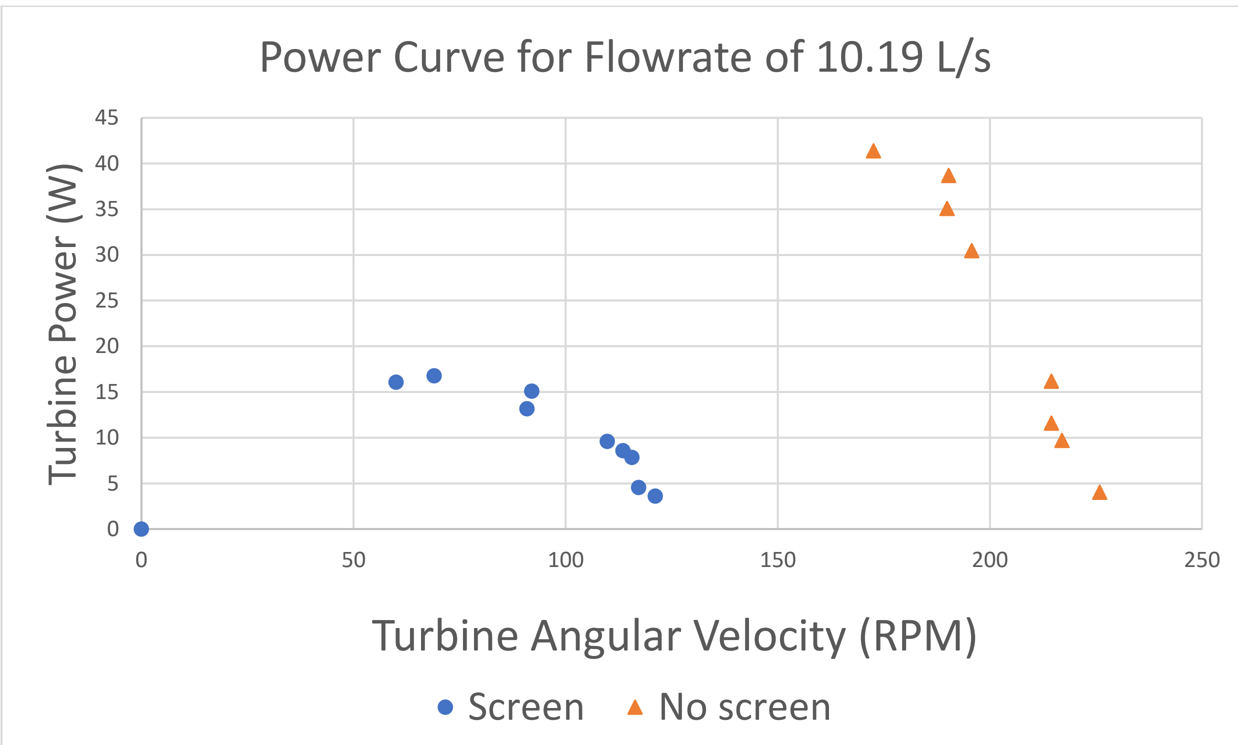

Figure 31: Power Curve at 10.19 L/s screen results comparison

Figure 32 shows the results from the test run at 14.48 L/s. Again, the screens reduced flow into the turbine which was to be expected. At 14.48 L/s, the screen blocked around 50% of the water going into the turbine.

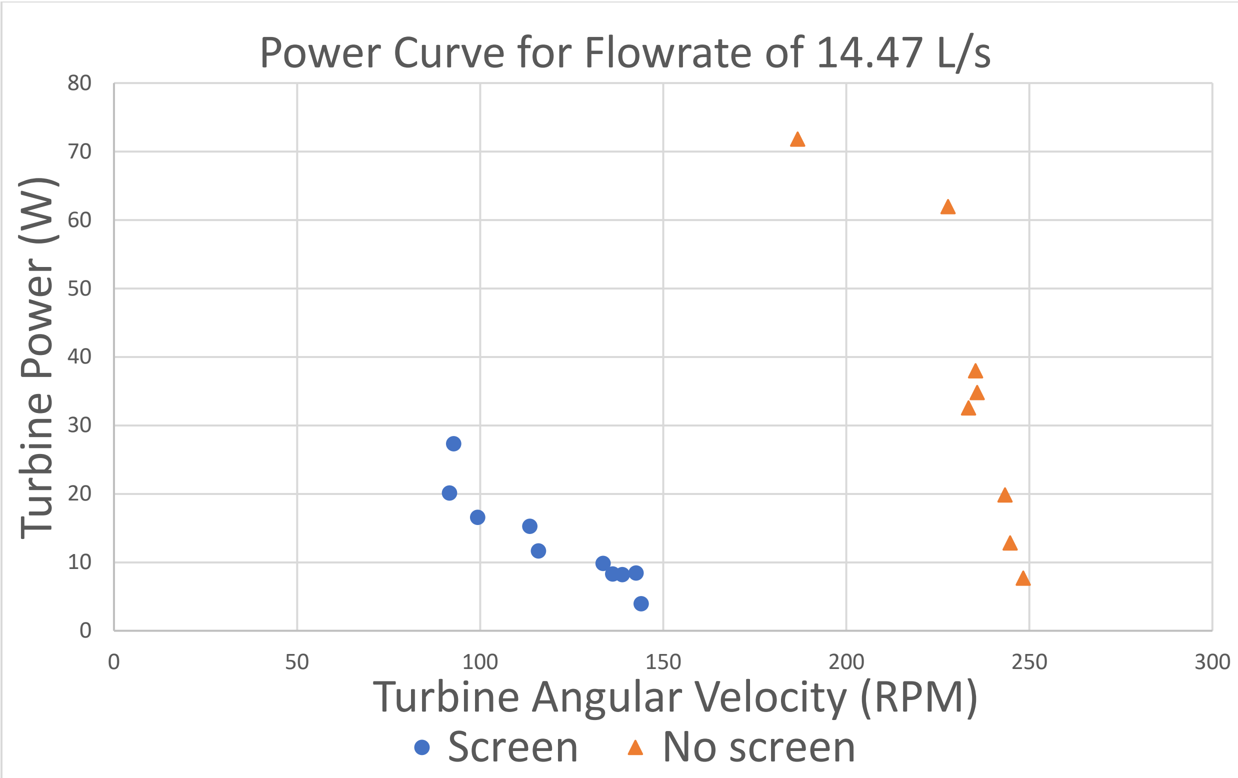

Figure 32: Power Curve at 14.48 L/s screen results comparison

One area of interested that future members could investigate should be screen design. Elgin, the company who manufactured the screen, developed a flat panel screen to set on the top of the inlet. The current model after testing showed that it blocked around 50% of the total water flow passing through the turbine. In order to have high efficiency, the screen will need to allow more water flow through the turbine., yet, it still must block dangerous debris.

Potential areas to investigate with future work would be new screens and changing the angle of the existing screen. The current turbine testing model requires a flat screen which is not effective. The existing turbine or screen could be angled to see if this would make any beneficial effect (Wahl, 2003). A Coanda-effect hydro screen is designed to work best at an angle to allow for the Coanda-effect to make its full impact. The turbine inlet could be changed to an angle to meet this requirement if it produced greater results.

Chapter 9: Conclusion

9.1: Contributions

There are two main areas that this project will contribute to help push forward the progress of renewable energy. The first is the continued testing on the Williams crossflow turbine for Central State University and Dr. Belloni's Hydro and Aero Energy Group. Central State University will be able to use the results from the tests to continue optimizing its design before commercialization. Next, other members of Dr. Belloni's team can use this report as a guideline for future testing. This will help speed up their testing process to develop future blades and screens.

The second area is developing different crossflow turbine testing techniques. This report outlines testing a crossflow turbine in a flume which is not a common testing facility. Other companies or research groups can use this as a guideline for future testing of crossflow turbines design for open channel flow.

9.2: Summary of Work

The first part of this project was focused on adjustments to the testing facility, examination of data recording techniques, and maintenance of the turbine. For adjustments to test testing facility, the flow shields (Figure 15) worked very well, guiding almost all of the flow through the turbine while still being removable to allow another testing in the flume. While examining the data recording techniques, a flaw was discovered in working with the stroboscope to get the angular velocity of the turbine. This was fixed by using a slow-motion camera as a secondary reference to find the exact range of the turbine's speed. Lastly, general maintenance of the turbine was address by realigning the belt drive, adjusting internal blade restrictions, and getting a new generator ordered for future testing.

The second part of the project was focused on testing the efficiency of the turbine by using two different blades, changing the flow path of the flume, and using a screen on the inlet of the turbine. After running both the J blade (Figure 21) and C blade (Figure 22) designs at three different flow rates, no significant difference could be determined between them. Most tests will need to be run to determine which blade design is best. Next, by using the flow shields, it was able to prove that 40% of the channel flume flow went passed through the turbine (Figure 26). In the original work performed by Dr. Sritharan (S. I. Sritharan, 2013), they had estimated that 50% of flow passed through the turbine. They had made assumptions that the water going under and around the weir was negligible. Yet, this accounts for 10% of the water flow in the flume. Lastly, the turbine was tested with a flat plate screen manufactured by Elgin. The results from these tests show that the screen blocked around 50% of the water into the turbine, reducing the power output from the turbine.

9.3: Future work

Based on the results from this project and the work done by Dr. Sritharan (S. I. Sritharan, 2013), the next team of students should investigate blade and screen design. For the turbine blades, more tests should be done on the existing two types to increase the efficiency of the system. Additionally, new blades can be manufactured based off work done by a CFD model. For the turbine screen, both screen style and angle should be addressed to increase flow into the turbine. This work should be done in collaboration with Elgin who manufactured the screen used in this project.

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